

AD-A192 603

DEPRESSED SWEATING DURING EXERCISE AT ALTITUDE(U) ARMY  
RESEARCH INST OF ENVIRONMENTAL MEDICINE NATICK MA  
M A KOLKA ET AL FEB 88 USARIEM-M-38/88

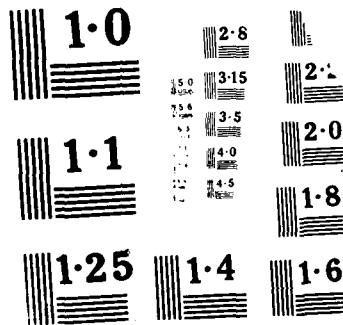
1/1

UNCLASSIFIED

F/G 6/10

NL





DTIC FILE COPY ①

Depressed sweating during exercise at altitude

Margaret A. Kolka, Lou A. Stephenson and Richard R. Gonzalez

United States Army Research Institute of Environmental  
Medicine, Natick, MA 01760-5007

Send offprint requests to:

Dr. M.A. Kolka  
USARIEM  
Kansas Street  
Natick, MA 01760-5007  
617-651-4849

DTIC  
ELECTE  
APR 01 1988  
S H D

DISTRIBUTION STATEMENT A

Approved for public release;  
Distribution unlimited

88 3 31 080

AD-A192603

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION / AVAILABILITY OF REPORT		
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE			Approved for public release; distribution is unlimited		
4. PERFORMING ORGANIZATION REPORT NUMBER(S)			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION US Army Res Inst of Env Med		6b. OFFICE SYMBOL (If applicable) SGRD-UE-MEP	7a. NAME OF MONITORING ORGANIZATION US Army Res Inst of Env Med		
6c. ADDRESS (City, State, and ZIP Code) Kansas St. Natick, MA 01760-5007			7b. ADDRESS (City, State, and ZIP Code) Kansas St. Natick, MA 01760-5007		
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Same as 6a.		8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c. ADDRESS (City, State, and ZIP Code) Same as 6c.			10. SOURCE OF FUNDING NUMBERS		
PROGRAM ELEMENT NO.		PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.	
		3E16287A879	879/BD	132	
11. TITLE (Include Security Classification) (U) Depressed sweating during exercise at altitude					
12. PERSONAL AUTHOR(S) Margaret A. Kolka, Lou A. Stephenson and Richard R. Gonzalez					
13a. TYPE OF REPORT Manuscript		13b. TIME COVERED FROM _____ TO _____		14. DATE OF REPORT (Year, Month, Day) February 1988	
15. PAGE COUNT 16					
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Altitude, exercise, hypobaria, temperature regulation, sweating		
19. ABSTRACT (Continue on reverse if necessary and identify by block number)					
<p>1. Acute exposure to moderate (552 torr) and high (428 torr) altitude resulted in a decrease in the thermosensitivity of arm, chest and thigh sweating during light and moderate exercise. This effect was not accompanied by any change in the esophageal temperature threshold for sweating onset at any of the three sites.</p> <p>2. Whole body wettedness was decreased an average of 23% at high altitude during light (40% <math>\dot{V}O_2</math> peak) and moderate (60% <math>\dot{V}O_2</math> peak) exercise. There was no change in mean weighted skin temperature at either moderate or high altitude.</p>					
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION		
22a. NAME OF RESPONSIBLE INDIVIDUAL Margaret A. Kolka, Ph.D			22b. TELEPHONE (Include Area Code) 617-651-4849		22c. OFFICE SYMBOL SGRD-UE-MEP

Abstract - 1. Acute exposure to moderate (552 torr) and high (428 torr) altitude resulted in a decrease in the thermosensitivity of arm, chest and thigh sweating during light and moderate exercise. This effect was not accompanied by any change in the esophageal temperature threshold for sweating onset at any of the three sites.

2. Whole body wettedness was decreased an average of 23% at high altitude during light (40%  $\dot{V}O_2$  peak) and moderate (60%  $\dot{V}O_2$  peak) exercise. There was no change in mean weighted skin temperature at either moderate or high altitude.

Key Word Index - Altitude; exercise; hypobaria; temperature regulation; sweating

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	<input type="checkbox"/>
By	
Date	
Availability Codes	
Avail. Codes	
Dist	
A-1	

## INTRODUCTION

The physical effects of a hypobaric environment, such as decreased air density, on the control of sweating in humans has not been extensively studied. During acute exposure to simulated altitude (Greenleaf et al., 1969) whole body sweating was elevated compared to sea level in men exercising at the same metabolic rate. In another study, which evaluated long term altitude exposure, the core temperature threshold for sweating onset was elevated compared to sea level (Raynaud et al., 1980). In an earlier paper (Kolka et al., 1987), we demonstrated that the gain of both local sweating and forearm cutaneous blood flow to increasing core temperature during exercise was suppressed by both moderate and high altitude in a comfortable environment. However, exposure to altitude is generally associated with a cool environmental temperature and the metabolic rate during exercise may be compromised by the level of hypoxia, thus bias may result in the experimental design of the study because exercise intensity may not be replicated between normobaria and hypobaria.

In the current study, we evaluated local sweating at three skin sites during exercise at sea level, moderate and high altitude. To further investigate the reported attenuation in sweating response seen during exercise at altitude, both a low and a moderate exercise intensity were evaluated in cool and comfortable environments.

## METHODS

Eight healthy subjects volunteered to participate in the experiments following approval of all procedures by the institutional review board. The characteristics of the subjects are given in Table 1. Prior to environmental testing, subjects were

oriented to all experimental procedures and performed peak aerobic power tests at  $P_B = 770$  torr (sea level),  $P_B = 552$  torr (8500 ft) and  $P_B = 428$  torr (15000 ft) in a random order at  $24^{\circ}\text{C}$ ; the subjects were not informed of the altitude during any test session. During these tests, the subject was seated behind the pedals of a cycle ergometer, such that the legs were parallel to the floor during exercise. The peak aerobic power was evaluated during continuously increasing resistance (30 W each 2 min) and was determined as stability in oxygen uptake ( $<150$  ml) with an increase in ergometer resistance. The four female subjects were tested only during the early follicular phase of the menstrual cycle (Stephenson and Kolka, 1985).

Experiments were conducted between 0800 h and 1200 h, with any one subject tested at the same time of day in all experiments to control for circadian variability in heat loss responses (Stephenson et al., 1984). On the day of an experiment, the subject reported to the hypobaric chamber, was weighed and sat in the chair of the cycle ergometer. The ambient temperature of the chamber was set to either  $20^{\circ}\text{C}$  or  $30^{\circ}\text{C}$  with an ambient water vapor pressure of 1.2 kPa. The subject swallowed a catheter containing a small thermocouple for the measurement of esophageal ( $T_{es}$ ) temperature (based on 25% of the subject's height adjusted for the highest temperature reading). Each subject drank approximately 200 ml of water during this procedure. Eight surface copper-constantan thermocouples were attached to the forehead, chest, back, upper arm, forearm, hand, thigh and calf for the calculation of a mean weighted skin ( $\bar{T}_{sk}$ ) temperature (Nishi and Gagge, 1970). Small dew-point sensors were attached to the chest, arm and thigh to measure local sweating rates from these areas. These sensors were

ventilated with air from the chamber ( $500 \text{ ml} \cdot \text{min}^{-1}$ ) and flow rates were calibrated in situ at the end of each experiment. Sweating rates were calculated as described previously (Graichen et al., 1982; Kolka et al., 1987).  $T_{es}$ ,  $\bar{T}_{sk}$ , and  $\dot{m}_s$  from all three sites were measured continuously during exercise. Heart rate from three chest leads was measured each five minutes during exercise. Skin wettedness (Gagge, 1972; Gonzalez et al., 1985) was calculated as the ratio of evaporative heat loss from the skin ( $E_{sk}$ ) to maximal evaporative power of the environment ( $E_{max}$ ) as:

$$w = (0.68 W \cdot g^{-1})(60)/m^2 / h_e(P_{s,sk} - P_a) \quad (\%)$$

where the first half of the equation transfers sweating rate in  $g \cdot \text{min}^{-1}$  to  $W \cdot m^2$  and in the second half of the equation,  $h_e$  is the evaporative heat transfer coefficient,  $P_{s,sk}$  is the saturated water vapor pressure at  $\bar{T}_{sk}$  and  $P_a$  is the ambient water vapor pressure.

The subject equilibrated to the environmental temperature and then the appropriate environment was simulated by decompression. The subject exercised at either 40 or 60% of the previously determined altitude-specific  $\dot{V}O_2$  peak for a period of 35 minutes. Each subject was tested on nine separate occasions as shown in Table 2. All combinations of exercise intensity, ambient temperature and altitude were counterbalanced. Metabolic rate was calculated from oxygen uptake measurements before exercise and frequently during the exercise bout.

The  $T_{es}$  threshold for sweating was analyzed for each experiment by analyzing the inflection point of the exercise transient for sweating to  $T_{es}$ . The exercise transient phase was that point in exercise where a rapid increase in sweating and  $T_{es}$  occurred. A regression equation was then calculated for each of

the three sweating sites for each of the 72 experiments. The  $T_{es}$  threshold for sweating was calculated where  $\dot{m}_s$  exceeded  $0.06 \text{ mg} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ . Unfortunately, exercise at 40%  $\dot{V}_{O_2}$  peak and  $20^\circ\text{C}$  caused little sweating and this analysis could not be made for all subjects, therefore data from the thermal steady-state during exercise are reported for these experiments. An analysis of variance with repeated measures (altitude by exercise intensity by temperature) was used where appropriate. Data in the RESULTS are presented as mean  $\pm$  standard deviation with significant differences at  $p < 0.05$ .

## RESULTS

Low intensity exercise at  $20^\circ\text{C}$  was an insufficient stimulus to consistently increase heat production enough to evaluate the transient responses of sweating at sea level or either of the altitudes. The subjects had sufficient heat exchange from the skin to the air, such that the low heat production from the exercise was readily dissipated. The average whole body sweating rates during these experiments was slightly less than  $4 \text{ g} \cdot \text{min}^{-1}$ . The data during 22 to 30 minutes of exercise for these experiments are presented in Table 3 along with that from the other two exercise-temperature combinations.

Resting esophageal temperature was relatively stable during the nine experiments due partly to strict adherence to circadian timing for individual experiments. However, at 428 torr, there was a slight decrease in resting  $T_{es}$  which averaged  $0.12^\circ\text{C}$  ( $p < 0.05$ ) compared to sea level experiments.

The average relative exercise intensity at which the subjects exercised was  $37 \pm 3\%$  for light exercise and  $55 \pm 3\%$  for moderate exercise at all three altitudes and both ambient temperatures. These relative intensities resulted in a  $0.34^\circ\text{C}$

increase in  $T_{es}$  during light exercise and  $0.58^{\circ}\text{C}$  increase in  $T_{es}$  during moderate exercise.

The mean weighted skin temperature was unchanged by altitude, but was as expected, related to ambient temperature. Mean skin temperature averaged  $34.5^{\circ}\text{C}$  during exercise at  $30^{\circ}\text{C}$  and  $31.3^{\circ}\text{C}$  during exercise at  $20^{\circ}\text{C}$ . Whole body sweating calculated from the change in body weight during an experiment was higher during moderate exercise in the cool environment and light exercise in the warm environment than light exercise in the cool environment.

Whole body wettedness ( $w$ ) calculated from the observed evaporative heat loss divided by the maximal evaporative power of the environment (corrected for altitude) decreased 5 and 34% at 552 torr and 428 torr, respectively during light exercise in the cool environment. During light exercise at  $30^{\circ}\text{C}$ ,  $w$  was decreased 16 and 25% at 552 torr and 428 torr. Finally,  $w$  was decreased by 3 and 28% during moderate exercise at  $20^{\circ}\text{C}$  at 552 and 428 torr, respectively.

The analysis from the individual regression equations for arm, chest and thigh sweating during increasing  $T_{es}$  for the eight subjects during exercise at three altitudes is given in Table 4. The  $T_{es}$  threshold for the onset of sweating was unchanged by altitude for any of the three sites measured. There were differences, however, in the  $T_{es}$  threshold from site to site, independent of altitude. A general suppression in thermosensitivity (gain) for sweating was apparent during acute altitude exposure, with no significant difference between the two altitudes. The thermosensitivity of chest sweating was reduced 36% ( $p < 0.05$ ) during moderate exercise at 552 torr. A similar suppression was observed during light exercise at moderate altitude. The thermosensitivity of arm sweating was reduced 42% during

both moderate and light exercise at 552 torr. The gain of thigh sweating was decreased 23 and 29% during moderate and light exercise at 552 torr.

## DISCUSSION

We evaluated sweating to changing esophageal temperature from three skin locations during acute exposure to simulated moderate or high altitude. The exercise intensity was adjusted at each altitude relative to the peak oxygen uptake measured at that specific altitude. Consequently, the change in esophageal temperature during exercise at a given intensity was similar at sea level, moderate and high altitude, thereby controlling heat production and allowing comparisons of sweating responses at the different altitudes.

The general suppression in the thermosensitivity of sweating during the exercise transient seen in the present study is consistent with changing peripheral input to the sweat gland. In our previous paper (Kolka et al., 1987), we had suggested that local skin influences, such as hydration status, skin temperature or heat transfer characteristics may have contributed to the suppression of sweating thermosensitivity. However, mean and local skin temperatures were not significantly affected by acute altitude exposure in the present study. We cannot directly address changes occurring at or just below the skin surface, except to recognize that whole body skin wettedness was reduced at both moderate and high altitude owing to the increased evaporative heat transfer coefficient observed with the reduced barometric pressure (Cena et al., 1982; Gonzalez and Cena, 1982).

The consistent increase in body temperature during a specific exercise intensity which occurred at all altitudes allowed an evaluation of whole body sweating with a matched internal thermal drive, thus no effect was apparent in

contrast to an earlier report (Greenleaf et al., 1969). In that earlier study, subjects exercised at 46%  $\dot{V}O_2$  peak at sea level contrasted with 66%  $\dot{V}O_2$  peak at 4000 m. The average increase in esophageal temperature from rest to exercise was 1.13°C at sea level and 1.37°C at 4000 m, associated with significantly increased sweating rate (16%). During acute altitude exposure, the mass transfer coefficient is increased thereby increasing evaporative heat loss for a given volume of fluid secreted by the sweat glands (Cena et al., 1982; Gonzalez and Cena, 1982). Similarly, dry heat exchange was augmented due to the decrease in air density allowing more free transfer of molecules from the body surface to the air. These physical properties of the hypobaric environment resulted in less requirement for regulatory sweating to achieve thermal equilibrium during exercise in the simulated hypobaric environments.

The responses of the four female subjects were not different from those of the four male subjects. All individuals were habitual exercisers and by controlling exercise intensity, time of day and menstrual cycle phase, it was possible to evaluate the genders simultaneously and show similar responses with regard to the control of sweating.

Similar responses to acute exposure to hypobaria were observed from all three different skin sites evaluated in the present study independent of exercise intensity or ambient temperature. It was apparent that differences existed in thermosensitivity and  $T_{es}$  threshold for the various sites measured, but this is not a new or unexpected finding (Bullard et al., 1967; Bullard et al., 1970; Nadel et al., 1971). In general, the threshold for sweating onset from the chest and thigh occurred at a lower esophageal temperature than the forearm in the present study.

Whatever the pattern of onset, it was consistent within a subject at sea level, 552 torr and 428 torr. The thermosensitivity was variable from site to site and from subject to subject. As previously suggested (Nadel et al., 1971), the density of sweat glands in the area and the individual innervation or recruitment pattern of those glands in each area combined with individual responses to central and peripheral thermal stimuli may be variable from subject to subject. The key observation from the present study was the consistent suppression in sweating thermosensitivity at all skin sites measured with acute hypobaric exposure.

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as official Department of the Army position, policy or decision, unless so designated by other official documentation. Human subjects participated in these studies after giving their informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

Approved for public release; distribution unlimited.

## REFERENCES

- Bullard, R.W., M.R. Banerjee, F. Chen, R. Elizondo and B.A. MacIntyre. (1970) Skin temperature and thermoregulatory sweating: a control systems approach. In: Physiological and Behavioral Temperature Regulation. Springfield, IL: Thomas, chapt. 40.
- Bullard, R.W., M.R. Banerjee and B.A. MacIntyre. (1967) The role of the skin in the regulation of eccrine sweating. *Int. J. Bioclimatol. Biometeorol.* 11: 93-104.
- Cena, K., R.R. Gonzalez and J.R. Sutton. (1982) A model for investigation of evaporative heat losses of man at rest and during exercise at high altitude (Abstract). In: *Hypoxia: Man at Altitude*. New York: Thieme-Stratton, p. 204.
- Gagge, A.P. (1972) Partitional calorimetry in the desert. In: *Physiological Adaptations: Desert and Mountain*. New York: Academic, p. 23-51.
- Gonzalez, R.R. and K. Cena. (1985) Evaluation of vapor permeation through garments during exercise. *J. Appl. Physiol.* 58: 928-935.
- Gonzalez, R.R., M.A. Kolka and L.A. Stephenson. (1985) Biophysics of heat exchange in hypobaric environments (Abstract). *Federation Proc.* 44: 1564.
- Graichen, H., R. Rascati and R.R. Gonzalez. (1982) Automatic dew-point temperature sensor. *J. Appl. Physiol.* 52: 1658-1660.

- Greenleaf, J.E., C.J. Greenleaf, D.H. Card and B. Saltin. (1969) Exercise-temperature regulation in man during acute exposure to simulated altitude. *J. Appl. Physiol.* 26: 290-296.
- Kolka, M.A., L.A. Stephenson, P.B. Rock and R.R. Gonzalez. (1987) Local sweating and cutaneous blood flow during exercise in hypobaric environments. *J. Appl. Physiol.* 62: 2224-2229.
- Nadel, E.R., J.W. Mitchell, B. Saltin and J.A.J. Stolwijk. (1971) Peripheral modifications to the central drive for sweating. *J. Appl. Physiol.* 31: 828-833.
- Nishi, Y., and A.P. Gagge. (1970) Direct evaluation of convective heat transfer coefficient by naphthalene sublimation. *J. Appl. Physiol.* 29: 830-838.
- Raynaud, J., J.-P. Martinaud and J. Durand. (1980) Upward shifting of the central temperature in adaptation to chronic heat and high altitude. *Proc. Int. Symp. Thermal Biol. Pecaz, Hungary*, p.285-287.
- Stephenson, L.A. and M.A. Kolka. (1985) Menstrual cycle phase and time of day alter the reference signal controlling arm blood flow and sweating. *Am. J. Physiol.* 249 (Regulatory Integrative Comp. Physiol.) R186-R191.
- Stephenson, L.A., C.B. Wenger, B.H.O'Donovan and E.R. Nadel. (1984) Circadian rhythm in sweating and cutaneous blood flow. *Am. J. Physiol.* (Regulatory Integrative Comp. Physiol.) R321-R324.

Table 1. Physical characteristics of the subjects.

	Sex	Age (yr)	SA <sub>2</sub> (m <sup>2</sup> )	Wt (kg)	$\dot{V}O_2$ peak (l•min <sup>-1</sup> )		
					770 Torr	552 Torr	428 Torr
1	M	24	1.77	69.8	3.76	3.57	2.80
2	M	33	1.99	80.0	2.77	2.68	2.77
3	M	25	1.87	73.9	2.49	2.58	2.21
4	M	27	1.89	73.6	4.06	3.37	2.85
5	F	19	1.68	64.7	2.60	2.25	1.90
6	F	24	1.65	60.9	2.20	1.87	1.59
7	F	25	1.95	82.5	2.83	2.72	2.57
8	F	29	1.73	63.0	2.61	2.37	2.22
MEAN		25.8	1.82	71.1	2.92	2.68	2.36
SD		4.1	0.13	7.9	0.65	0.56	0.46

Table 2. Experimental design of the study. Each subject participated in one experiment in each of the nine conditions presented. Each experiment consisted of an equilibration period (rest) and 35 minutes of seated cycle exercise at the requisite temperature and exercise intensity.

	<u>Sea Level</u>	<u>2593m (552 Torr)</u>	<u>4575m (428 Torr)</u>
<u>20°C</u>	40% $\dot{V}O_2$ peak	40% $\dot{V}O_2$ peak	40% $\dot{V}O_2$ peak
<u>20°C</u>	60% $\dot{V}O_2$ peak	60% $\dot{V}O_2$ peak	60% $\dot{V}O_2$ peak
<u>30°C</u>	40% $\dot{V}O_2$ peak	40% $\dot{V}O_2$ peak	40% $\dot{V}O_2$ peak

Table 3. Mean  $\pm$  SD data collected during exercise (22-30 min) at sea level, moderate and high altitude on eight subjects during light (40%  $\dot{V}O_2$  peak) and moderate (60%  $\dot{V}O_2$  peak) exercise at both 20°C and 30°C.

	<u>Sea Level</u>			<u>552 torr</u>			<u>428 torr</u>		
	<u>60/20</u>	<u>40/30</u>	<u>40/20</u>	<u>60/20</u>	<u>40/30</u>	<u>40/20</u>	<u>60/20</u>	<u>40/30</u>	<u>40/20</u>
$T_{es}$	37.11 (.17)	36.93 (.13)	36.93 (.31)	37.19 (.20)	37.00 (.23)	36.96 (.26)	37.13 (.16)	36.98 (.20)	36.77* (.35)
$T_{sk}$	31.02 (.77)	34.42# (.35)	31.04 (.77)	31.41 (.75)	34.48# (.38)	31.26 (.52)	31.69 (.39)	34.59# (.76)	31.53 (.48)
$\Delta T_{es}$	0.50	0.33	0.33	0.54	0.39	0.29	0.70	0.43	0.29
$\dot{V}O_2$	1.55 (.30)	0.98 (.17)	1.03 (.13)	1.42 (.29)	0.95 (.17)	0.99 (.19)	1.39 (.33)	1.02 (.19)	0.92 (.17)
$\dot{M}_s, g \cdot min^{-1}$	8.0 (3.4)	8.1 (4.0)	3.7** (1.1)	8.0 (1.4)	6.1 (1.8)	3.7** (1.0)	6.2 (1.7)	7.1 (2.5)	4.0** (2.0)
$T_{es, rest}$	36.61 (.20)	36.63 (.16)	36.60 (.19)	36.65 (.24)	36.61 (.22)	36.67 (.29)	36.44* (.23)	36.55 (.15)	36.48* (.23)

\* Different from sea level,  $p < 0.05$ .

# Different from 20°C,  $p < 0.05$ .

Different from 60%, 20°C and 40%, 30°C,  $p < 0.05$ .

Table 4. Mean ( $\pm$  SD) esophageal temperature for the onset of sweating ( $T_{es}$ ) and thermosensitivity ( $\dot{m}_s/T_{es}$ ) for the eight subjects during light and moderate exercise at three altitudes.

	<u>Sea Level</u>	<u>552 torr</u>	<u>428 torr</u>
<u>60%, 20°C</u>			
CHEST $T_{es}, ^\circ\text{C}$	36.52 (0.45)	36.49 (0.33)	36.44 (0.25)
$\dot{m}_s/T_{es}$	1.04 (0.40)	0.67 (0.27)*	0.60 (0.20)*
ARM $T_{es}, ^\circ\text{C}$	36.62 (0.30)	36.61 (0.37)	36.51 (0.27)
$\dot{m}_s/T_{es}$	1.84 (0.67)	1.07 (0.63)*	0.90 (0.11)*
THIGH $T_{es}, ^\circ\text{C}$	36.56 (0.38)	36.42 (0.31)	36.27 (0.25)
$\dot{m}_s/T_{es}$	1.31 (0.41)	1.01 (0.21)*	0.95 (0.31)*
<u>40%, 30°C</u>			
CHEST $T_{es}, ^\circ\text{C}$	36.46 (0.28)	36.62 (0.22)	36.53 (0.20)
$\dot{m}_s/T_{es}$	1.27 (0.69)	0.82 (0.42)*	0.67 (0.29)*
ARM $T_{es}, ^\circ\text{C}$	36.57 (0.23)	36.81 (0.20)	36.70 (0.14)
$\dot{m}_s/T_{es}$	1.48 (1.21)	0.86 (0.49)*	0.96 (0.42)*
THIGH $T_{es}, ^\circ\text{C}$	36.41 (0.16)	36.54 (0.22)	36.49 (0.24)
$\dot{m}_s/T_{es}$	2.01 (1.25)	1.43 (0.34)*	0.93 (0.26)*

\* Different from sea level  $p < 0.05$ .

## TABLE LEGENDS

Table 1. Physical characteristics of the subjects.

Table 2. Experimental design of the study. Each subject participated in one experiment at each of the nine conditions presented. Each experiment consisted of an equilibration period (rest) and 35 minutes of seated cycle exercise at the requisite temperature and exercise intensity.

Table 3. Mean  $\pm$  SD data collected during exercise (22-30 min) at sea level, moderate and high altitude on eight subjects during light (40%  $\dot{V}O_2$  peak) and moderate (60%  $\dot{V}O_2$  peak) exercise at both 20°C and 30°C.

Table 4. Mean ( $\pm$  SD) esophageal temperature for the onset of sweating ( $T_{es}$ ) and thermosensitivity ( $m_s/T_{es}$ ) for the eight subjects during light and moderate exercise at three altitudes.

END

DATE

FILMED

DTIC

6-88